



Traffic impact assessment of a large-scale residential development on urban collector roads

Irwan Amar^{1,*}, Syamsul Bahri², Muhammad Hatta³

¹ Safety Engineering Study Program, Institut Teknologi dan Kesehatan Tri Tunas Nasional, Makassar, South Sulawesi 90235, Indonesia;

² Department of Public Health, Universitas Mega Buana Palopo, Palopo, South Sulawesi 91913, Indonesia;

³ Public Health Study Program, Sekolah Tinggi Ilmu Kesehatan Makassar, Makassar, South Sulawesi 90241, Indonesia.

*Correspondence: irwanamar92@gmail.com

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ABSTRACT

Background: Rapid residential expansion at metropolitan fringes can increase traffic demand on collector roads, create access conflicts, and reduce operational reliability at median openings. This study assessed the traffic implications of the planned Sunville Residence development on Tun Abdul Razak Road in Paccinongang, Gowa Regency, Indonesia. **Methods:** The analysis synthesized a 2025 traffic impact study covering road geometry, road capacity, weekday and weekend traffic volumes, degree of saturation, level of service, U-turn maneuver times and queue ratios, trip production and attraction, directional distribution, mode share, network loading, parking demand, public transport access, pedestrian facilities, and forecasts to 2032. Capacity calculations followed the Indonesian Road Capacity Guidelines, while the development scenario added approximately 160 passenger-car units per hour and applied an annual traffic growth rate of 2.98%. **Findings:** The divided four-lane collector had a reported capacity of 6,314.9 passenger-car units per hour. Existing weekday peak degree of saturation was 0.52 on TAR and 0.55 on TAR II. With development, these values increased to 0.54 and 0.57. Medium vehicles produced the highest U-turn queue ratios, reaching 0.58 at U-turn I and 0.31 at U-turn II. Weekday peak development traffic reached 164 passenger-car units per hour, and 77.3% of generated movements were assigned toward Makassar. Motorcycles represented 84.1% of the observed daily vehicle count. By 2032, weekday peak saturation was projected to reach 0.65 on TAR and 0.69 on TAR II, with the reported level of service declining to D on the most critical weekday periods. Commercial and shophouse uses required 320 parking spaces, including 214 motorcycle, 101 car, and 5 truck spaces. **Conclusion:** The road network can accommodate initial development traffic, but the limited operational reserve at TAR II, concentrated Makassar-oriented trips, U-turn queuing, and motorcycle-dominated flow require staged access management, safe pedestrian-transit connections, parking control, and annual performance monitoring. **Novelty/Originality of this article:** This study integrates link performance, median-opening operations, travel-demand components, multimodal access, parking, safety, and pavement-risk considerations within one development-level assessment for a motorcycle-dominated peri-urban corridor.

KEYWORDS: residential development; traffic forecasting; traffic impact assessment; urban collector roads; u-turn operations.

1. Introduction

Large residential projects influence transport systems through additional household trips, employee and visitor movements, service vehicles, commercial activity, and construction logistics (Weisbrod, 2008). The effect extends beyond the number of generated vehicles. A new access can change lane use, turning movements, median-opening

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demand, pedestrian crossing patterns, public transport access, parking behavior, and the distribution of traffic across adjacent links (Cantisani et al., 2023). Traffic impact assessment therefore links land-use development with operational, safety, and multimodal performance before construction and during operation (Soltani et al., 2025).

Road capacity analysis provides the basic screening framework for development impacts (Roess & Prassas, 2014). The Indonesian Road Capacity Guidelines define capacity and operational performance through traffic flow, degree of saturation, speed, and travel time for urban roads (Bang et al., 1991). The highway capacity manual uses related measures to describe the quality of traffic operations while recognizing that acceptable performance depends on facility type, demand variability, and multimodal context (Bang et al., 1991; Roess & Prassas, 2014). A modest increase in the volume-to-capacity ratio may appear acceptable in the opening year but can reduce resilience to incidents, construction activity, parking friction, and future traffic growth (Cantisani et al., 2023; Sinurat et al., 2026).

Peri-urban corridors in Indonesian metropolitan regions often carry heterogeneous traffic with a high motorcycle share. Motorcycles use less static road space than passenger cars but exhibit filtering, lateral movement, short headways, and distinct gap-acceptance behavior (Towers, 2024). These characteristics complicate the conversion of observed vehicle counts into passenger-car units and can affect the reliability of conventional capacity procedures. A development-level assessment must therefore preserve the observed vehicle composition and avoid interpreting passenger-car-unit results as simple vehicle counts (Cong et al., 2005).

Median openings and U-turns create a second layer of operational risk. Drivers must decelerate, wait for an acceptable gap, complete a low-speed turning maneuver, and merge into the opposing traffic stream (Mohapatra & Dey, 2018). The available capacity depends on conflicting flow, critical gap, follow-up time, vehicle dimensions, median geometry, and driver behavior (Mohan & Chandra, 2021). Research has shown that U-turn capacity decreases when opposing flow rises and that heavy or medium vehicles require longer maneuver times than motorcycles. Queue growth at a median opening can block through lanes and shift risk from the opening itself to rear-end and sideswipe conflicts upstream (Ewing & Cervero, 2017).

Travel-demand analysis explains how a development produces its operational effect (Mohapatra & Dey, 2018). Trip generation estimates the number of entering and exiting movements, trip distribution assigns those movements to directions or zones, mode choice determines the share using each transport mode, and network loading places those trips on specific links (Sunggiardi & Putranto, 2011). Standard trip-generation manuals provide empirical rates, but local calibration remains necessary because household size, income, land-use mix, motorcycle ownership, transit availability, and parking supply differ across regions (Ewing & Dumbaugh, 2009). The built environment and residential location also shape travel behavior, although researchers must separate causal effects from residential self-selection (Ewing & Handy, 2009; Reed et al., 2018).

Parking policy strongly influences traffic generated by commercial and residential land uses (Shoup, 2006). Excessive parking supply can lower the perceived cost of private vehicle use, while inadequate off-street supply can produce cruising, spillover parking, and side friction on the road network (Marsden, 2006). Parking analysis should therefore consider demand, vehicle composition, turnover, loading activity, and the relationship between parking and trip generation rather than treating parking as an isolated site-design variable (Manville & Shoup, 2005).

Multimodal access can moderate development traffic. Short walking distances to public transport, connected sidewalks, safe crossings, and direct internal routes can support non-car travel (Cervero & Kockelman, 1997; Ewing & Cervero, 2010). Transit-oriented and walkable environments correlate with lower vehicle travel when land-use density, diversity, design, destination accessibility, and transit proximity work together. Indonesian metropolitan experience also shows that transit-oriented development requires coordination among land use, station access, pedestrian quality, and local governance

rather than proximity alone (Hasibuan & Mulyani, 2022). Traffic safety and pavement condition complete the assessment. Access points create crossing, merging, and deceleration conflicts. Road form, operating speed, lighting, pedestrian exposure, and access density influence crash risk (Dumbaugh & Rae, 2009; Ewing & Dumbaugh, 2009). Construction traffic can also impose repeated heavy loads and damage pavement edges, shoulders, and concrete joints. A traffic management plan must schedule deliveries, control loads, maintain access visibility, protect pedestrians, and establish responsibility for road repair (Chełstowska et al., 2025).

The present study evaluates the 2025 traffic baseline and projected impacts of Sunville Residence on Tun Abdul Razak Road in Paccinongang, Gowa Regency. It addresses five questions: first, how much operational reserve exists on the affected road segments; second, which U-turn and vehicle classes create the greatest queue pressure; third, how the development's trips distribute by time, direction, and vehicle class; fourth, when forecast traffic begins to reduce service quality; and fifth, which access, parking, pedestrian, transit, safety, and pavement measures should accompany the development. The study does not claim novelty from new field-data collection. Its contribution is methodological and integrative. It reorganizes the existing 2025 traffic-impact evidence into a single assessment chain linking segment capacity, U-turn performance, travel-demand components, vehicle composition, network loading, multimodal access, parking, safety, construction logistics, pavement risk, and forecast monitoring. The analytical workflow is made auditable by stating source values, equations, units, scenario assumptions, arithmetic checks, and the distinction between source-reported results and author-derived summaries. Reproducibility is therefore defined at the level of the reported inputs and calculations rather than the unavailable raw survey records.

2. Methods

2.1 Study setting and data source

The study area lies on Tun Abdul Razak (TAR) Road in Paccinongang, Somba Opu District, Gowa Regency, South Sulawesi. The corridor connects Gowa with Makassar and functions as a provincial primary collector. The traffic impact source document divided the affected corridor into TAR and TAR II to represent the segments adjacent to the proposed access and its surrounding operating environment. Both segments were analyzed as a four-lane divided road with two lanes in each direction.

This article uses secondary data from the 2025 traffic impact assessment prepared for the Sunville Residence development. The source included road geometry, traffic volumes, capacity factors, weekday and weekend performance, field photographs, U-turn locations, maneuver times, queue ratios, trip production and attraction, directional assignment, vehicle composition, network loading, annual forecasts, parking estimates, public transport access, pedestrian plans, internal circulation, traffic-safety measures, and construction-traffic risk. No new field survey was conducted for this journal article. The analytical contribution is the structured integration and re-analysis of these source outputs within one development-level traffic-impact framework.

Analytical reproducibility was addressed through a traceability protocol. First, source-reported values were retained with their stated units, time periods, and scenario labels. Second, capacity, degree-of-saturation, U-turn service-rate, directional-allocation, and project-loading calculations were checked against the equations and numerical inputs reported in the source. Third, author-derived summaries, including maxima, mean queue ratios, directional splits, and cross-table comparisons, were recalculated from the reported values. Fourth, undocumented assumptions and internal inconsistencies were identified explicitly rather than silently corrected. This protocol allows another analyst to repeat the journal-level calculations from the reported inputs and to distinguish reproduced source results from new analytical interpretation.

The source document did not provide individual raw traffic-count sheets, survey dates for each traffic period, confidence intervals, speed distributions, crash records, or microsimulation files. Reproducibility is therefore limited to the reported-input and analytical-workflow level. The article does not claim to reproduce the original field survey, estimate sampling uncertainty, or make statistical inference beyond the reported observations. This boundary is stated explicitly to avoid presenting secondary re-analysis as new empirical field evidence.

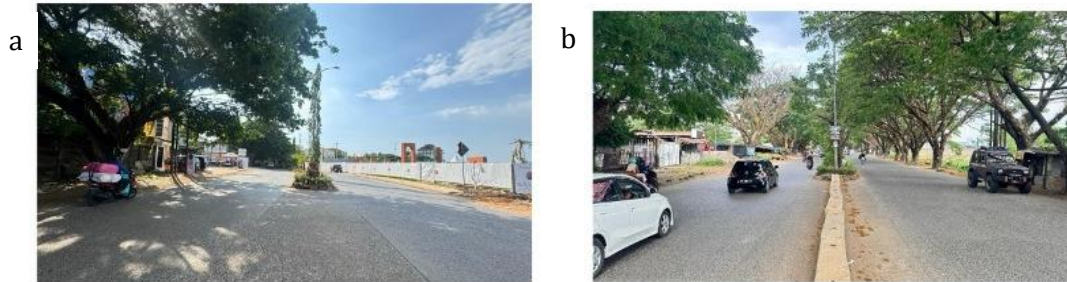


Fig. 1. Existing conditions of the affected Tun Abdul Razak Road segments: (a) TAR and (b) TAR II

2.2 Road capacity and operational performance

The road-capacity calculation followed the structure of the Indonesian urban-road procedure (Munawar et al., 2017). The base capacity was adjusted for lane width, directional separation, side friction and shoulder conditions, and city size. The reported factors were a base capacity of 6,600 passenger-car units per hour, a lane-width factor of 1.04, a directional-separation factor of 1.00, a side-friction factor of 0.92, and a city-size factor of 1.00.

$$C = C_0 \times FC_{LJ} \times FC_{PA} \times FC_{HS} \times FC_{UK} \quad (\text{Eq. 1})$$

where C is adjusted road capacity, C_0 is base capacity, and the FC terms are the reported adjustment factors.

Multiplication gives 6,314.9 passenger-car units per hour, rounded to 6,315 in the performance tables. Operational loading was measured as the degree of saturation, Q/C .

$$D_s = Q / C \quad (\text{Eq. 2})$$

The study compared weekday and weekend peak and average conditions for TAR and TAR II. It retained the level-of-service categories stated in the source document. Because the source applied letter grades directly to the reported degree of saturation, this article reports those grades without recalibrating them to a different manual (Lam & Huang, 1992).

2.3 U-turn performance assessment

Two median openings serve development-related turning movements. Vehicles leaving the site and travelling toward Makassar must first turn left and use U-turn I approximately 50 m from the access. Vehicles approaching from the opposite direction pass the site, use U-turn II near the bridge, and return to enter the development. The source calculated theoretical service rate by dividing 3,600 s by average maneuver time for motorcycles, medium vehicles, and heavy vehicles.

$$S_i = 3600 / t_i \quad (\text{Eq. 3})$$

reported because the base-year rounding and treatment of project traffic were not fully documented. To test forecast sensitivity, this article additionally applies annual growth rates of 2.00%, 2.98%, and 4.00% to the reported 2025 weekday Q/C values. The 2.00% and 4.00% cases are author-defined planning scenarios that bracket the source rate and are not statistical confidence bounds. For each sensitivity case, the year- y Q/C is calculated as the 2025 Q/C multiplied by $(1 + g)^{(y-2025)}$, with road capacity held constant. The 2.98% calculation reproduces the reported 2032 values after rounding and therefore provides an arithmetic consistency check.

2.6 Parking, transit, pedestrian, safety, and pavement review

Parking demand followed the Directorate General of Land Transportation area-based guidance for commercial land uses. Residential parking was assumed to be provided within each dwelling. The shophouse area covered 12,804 m² and the commercial area covered 17,000 m². The source converted these areas into units of 100 m² and interpolated parking demand between guideline values. It then allocated the total requirement by vehicle type (Surya et al., 2020).

The multimodal review considered the reported 130 m walking distance from the development to the nearest Teman Bus stop, the internal sidewalk widths, crossing needs on Tun Abdul Razak Road, and the relationship between internal circulation and the external collector. The safety review identified access conflicts, queue-related rear-end risk, pedestrian exposure, lighting and signing needs, and the effect of repeated construction truck movements. The source estimated 14,031 construction hauling trips, averaging about 125 trips per day.

3. Results and discussion

3.1 Road geometry, capacity, and baseline performance

Tun Abdul Razak Road has four lanes, two directions, and a median. The reported paved width is 15 m, the median is 2.75 m, the average shoulder is 0.5 m, the alignment is flat to gently graded, and the pavement is concrete. The external road lacks a continuous sidewalk at the project frontage. These characteristics provide substantial through capacity but create a discontinuity between the project's planned internal pedestrian network and the external corridor.

Table 1. Geometric and capacity characteristics of the affected corridor

Characteristic	Reported value
Road type	4/2 divided
Function	Primary collector
Administrative status	Provincial road
Paved width	15 m
Average shoulder width	0.5 m
Median width	2.75 m
Alignment	Flat/gentle
Pavement	Concrete
Adjusted capacity	6,314.9 PCU/h

The capacity calculation is internally consistent: $6,600 \times 1.04 \times 1.00 \times 0.92 \times 1.00$ equals 6,314.9 passenger-car units per hour. Baseline weekday peak Q/C reached 0.52 on TAR and 0.55 on TAR II. Weekend peak values were lower at 0.44 and 0.47. TAR II carried 192 more passenger-car units per hour than TAR during the weekday peak and had 0.03 less operational reserve. The pattern identifies TAR II as the critical segment before project loading.

The baseline results do not indicate oversaturation. They do show that weekday conditions are materially more demanding than weekend conditions. The difference

between weekday and weekend peak Q/C is 0.08 on both segments. The average-period values remain close to the peaks, especially on TAR II, where weekday average Q/C is 0.49. This narrow peak-to-average difference suggests that traffic pressure extends beyond a single short interval and that management should cover the broader afternoon period.

Table 2. Baseline traffic performance

Segment	Period	Flow (PCU/h)	Q/C	LOS
TAR	Weekday peak	3,268	0.52	C
TAR	Weekday average	2,944	0.47	C
TAR	Weekend peak	2,787	0.44	C
TAR	Weekend average	2,466	0.39	B
TAR II	Weekday peak	3,460	0.55	C
TAR II	Weekday average	3,079	0.49	C
TAR II	Weekend peak	2,958	0.47	C
TAR II	Weekend average	2,587	0.41	C

Capacity indicators require contextual interpretation. A Q/C below one does not guarantee reliable flow when side friction, turning queues, bus stopping, access maneuvers, or incidents occupy a through lane. The highway capacity manual (HCM) and Indonesian road capacity guidelines/*pedoman kapasitas jalan Indonesia* (PKJI) both treat capacity analysis as part of a wider performance assessment rather than a substitute for field observation. The absence of an external sidewalk also means that motor-vehicle performance alone cannot define acceptable corridor conditions.

3.2 U-turn operation and queue pressure

Motorcycle maneuver times ranged from 5.0 to 6.9 s in the reported service table, producing nominal service rates from 522 to 720 vehicles per hour. Medium-vehicle times ranged from 11.6 to 16.0 s, with service rates from 225 to 311 vehicles per hour. Heavy-vehicle times ranged from 11.6 to 22.3 s, with service rates from 162 to 311 vehicles per hour. The lower service rate of larger vehicles reflects their wider turning path and longer occupation of the median opening.

The source reproduced the same maneuver-time and nominal-service table for U-turn I and U-turn II. That duplication prevents an independent comparison of geometry-specific service rates. The queue-ratio tables, however, differentiate the two facilities. U-turn I is consistently more critical, particularly for medium vehicles on weekdays. Its mean queue ratio was 0.38 and its maximum reached 0.58 at 17:00-18:00. The corresponding U-turn II values were 0.19 and 0.29. The weekday medium-vehicle queue pressure at U-turn I was therefore twice the maximum at U-turn II.

Table 3. Summary of reported U-turn queue ratios

Facility	Day	Vehicle class	Mean P	Maximum P
U-turn I	Weekday	Motorcycle	0.32	0.45
U-turn I	Weekday	Medium vehicle	0.38	0.58
U-turn I	Weekday	Heavy vehicle	0.05	0.13
U-turn I	Weekend	Motorcycle	0.25	0.36
U-turn I	Weekend	Medium vehicle	0.30	0.49
U-turn I	Weekend	Heavy vehicle	0.02	0.04
U-turn II	Weekday	Motorcycle	0.16	0.22
U-turn II	Weekday	Medium vehicle	0.19	0.29
U-turn II	Weekday	Heavy vehicle	0.02	0.07
U-turn II	Weekend	Motorcycle	0.18	0.26
U-turn II	Weekend	Medium vehicle	0.19	0.31
U-turn II	Weekend	Heavy vehicle	0.01	0.03

The peak at U-turn I coincides with the main weekday attraction peak. This temporal overlap matters because entering development traffic and existing corridor traffic compete

for the same median-opening capacity. A queue ratio of 0.58 does not indicate complete saturation, but it reduces the margin for random arrival clusters, slow heavy vehicles, and hesitant gap acceptance. U-turn studies show that capacity estimates are sensitive to conflicting flow and local driver behavior, so field validation after initial occupancy is necessary (Al-Masaeid, 1999; Mohapatra et al., 2018; Elsenhwy et al., 2023).

Access management should reduce dependence on the most constrained movement. The proposed left-in/left-out arrangement limits direct crossing conflicts at the site access, but it transfers demand to median openings. The design should provide adequate deceleration storage, clear sight distance, protected waiting space, and enforcement against informal stopping near the openings. An operational trigger can be set for review when the medium-vehicle queue ratio at U-turn I repeatedly exceeds the current maximum or when queues enter the through lane during the 17:00-18:00 period.

3.3 Development trips, direction, and vehicle composition

The weekday maximum production was 75 passenger-car units per hour at 15:00-16:00, while maximum attraction was 89 passenger-car units per hour at 17:00-18:00. The combined maxima equal 164 passenger-car units per hour, although they occur in adjacent rather than identical hours. Weekend production and attraction both reached 65 passenger-car units per hour at 17:00-18:00, producing a combined peak of 130 passenger-car units per hour.

Table 4. Reported trip production and attraction

Day	Movement	Maximum (PCU/h)	Time	Minimum (PCU/h)	Time
Weekday	Production	75	15:00-16:00	49	11:00-12:00
Weekday	Attraction	89	17:00-18:00	43	07:00-08:00
Weekend	Production	65	17:00-18:00	36	10:00-11:00
Weekend	Attraction	65	17:00-18:00	24	07:00-08:00

The weekday time pattern reflects different activity types within a mixed residential-commercial development. Production peaks earlier, consistent with outbound movements from residents, workers, or visitors, while attraction peaks in the evening when residents return and commercial activity remains active. The operational plan should therefore avoid scheduling deliveries or waste collection during 15:00-18:00 because service vehicles would overlap with both production and attraction peaks.

Directional assignment places 77.3% of movements toward Makassar and 22.7% toward Gowa. At the weekday maximum, this produces 58 Makassar-bound and 17 Gowa-bound production movements, plus 69 Makassar-origin and 20 Gowa-origin attraction movements. These values should be interpreted as scenario allocations based on a transferred analogy, not as measured origin-destination behavior of future Sunville residents. Even with this limitation, the assumed Makassar concentration identifies the directional movements that require the closest operational attention, particularly at the median openings. Post-occupancy observations should confirm whether this concentration persists and should replace the assumed split if a materially different pattern emerges.

Table 5. Directional distribution of maximum development traffic

Movement	Total (PCU/h)	Makassar direction	Gowa direction
Weekday production	75	58	17
Weekday attraction	89	69	20
Weekend production	65	50	15
Weekend attraction	65	50	15

Note: 77.3% Makassar and 22.7% Gowa.

The vehicle count was strongly motorcycle-dominated. Motorcycles formed 84.1% of 45,312 daily vehicles, compared with 14.1% medium vehicles and 1.8% heavy vehicles. This

composition supports the use of local passenger-car equivalency factors and close observation of lateral movement. Motorcycle dominance also affects safety because riders interact with turning vehicles, pedestrian crossings, bus stops, and access queues in smaller gaps than car-only models represent (Minh et al., 2005; Wedagama, 2019; Prasetijo et al., 2011).

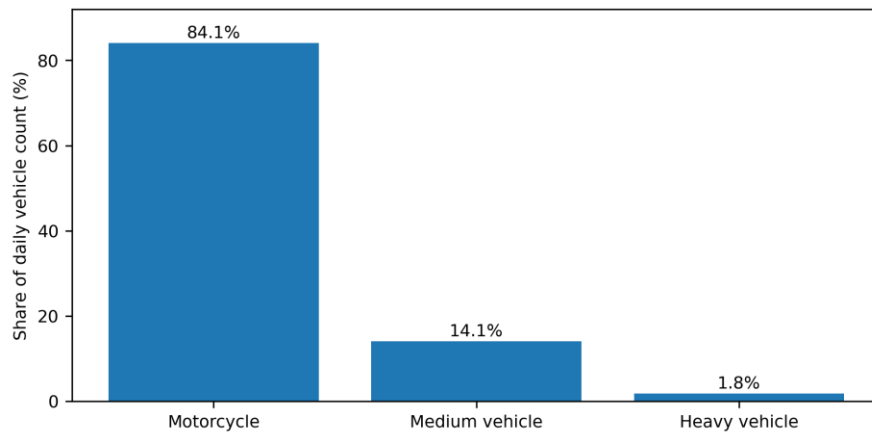


Fig. 3. Observed vehicle composition on Tun Abdul Razak Road

3.4 Immediate network loading

Adding project traffic raised weekday peak Q/C from 0.52 to 0.54 on TAR and from 0.55 to 0.57 on TAR II. Weekend peak Q/C increased from 0.44 to 0.46 on TAR and from 0.47 to 0.49 on TAR II. The immediate increment was 0.02 in every peak case. This uniform change is consistent with adding approximately 130 to 160 passenger-car units per hour to a capacity of about 6,315 passenger-car units per hour.

Table 6. Traffic performance with the development in the opening scenario

Segment	Period	With-project flow (PCU/h)	Q/C	LOS
TAR	Weekday peak	3,428	0.54	C
TAR	Weekday average	3,104	0.49	C
TAR	Weekend peak	2,917	0.46	C
TAR	Weekend average	2,596	0.41	C
TAR II	Weekday peak	3,620	0.57	C
TAR II	Weekday average	3,239	0.51	C
TAR II	Weekend peak	3,088	0.49	C
TAR II	Weekend average	2,717	0.43	C

The opening-year impact is operationally modest at link level. The project does not change the reported level-of-service letter for the four peak cases. Nevertheless, the result should not be interpreted as absence of impact. Link Q/C averages the effect over a road segment, whereas access maneuvers and U-turn queues occur at specific points. The source data already show a higher local queue ratio at U-turn I than the 0.02 link-level change would suggest. This contrast demonstrates why a traffic impact study should combine segment and access analyses.

The with-development weekday peak flow on TAR II is 3,620 passenger-car units per hour. The remaining nominal capacity is 2,695 passenger-car units per hour, but this figure does not represent usable site-access capacity. The through corridor must serve existing traffic, U-turn movements, bus activity, random fluctuations, and future growth. Development approval should therefore tie occupancy stages to monitored performance rather than rely only on the opening-year Q/C.

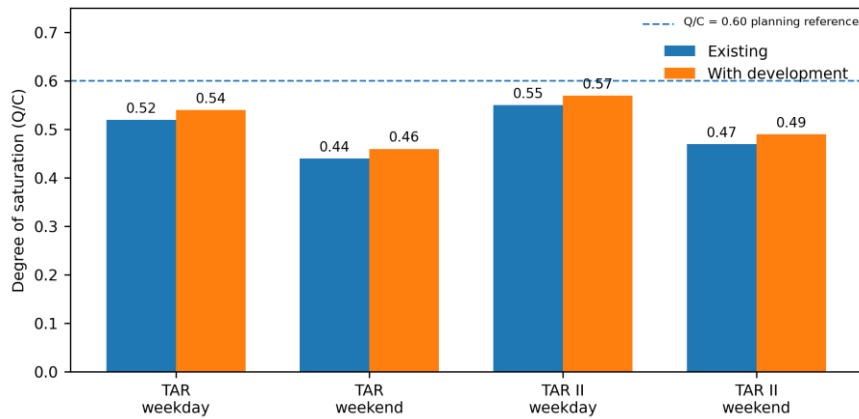


Fig. 4. Comparison of existing and with-development peak Q/C values. The dashed line denotes Q/C = 0.60 as a planning reference, not a level of service (LOS) threshold

3.5 Forecast performance to 2032

Table 7. Reported weekday Q/C forecast, 2025-2032

Scenario	2025	2026	2027	2028	2029	2030	2031	2032
TAR weekday peak	0.53	0.55	0.56	0.58	0.60	0.62	0.63	0.65
TAR weekday average	0.48	0.49	0.51	0.52	0.54	0.56	0.57	0.59
TAR II weekday peak	0.56	0.58	0.60	0.61	0.63	0.65	0.67	0.69
TAR II weekday average	0.50	0.52	0.53	0.55	0.56	0.58	0.60	0.62

(Traffic impact assessment, 2025)

The reported forecast shows continuous growth in every scenario. TAR weekday peak Q/C rises from 0.53 in 2025 to 0.65 in 2032. TAR II weekday peak Q/C rises from 0.56 to 0.69. Weekend peak values remain lower, reaching 0.56 on TAR and 0.59 on TAR II in 2032. The critical difference is not only the final value but the timing of the reported level-of-service transition. TAR II weekday peak changes from C to D in 2028, while TAR weekday peak changes to D in 2030. Accordingly, 2028 is used consistently throughout this manuscript as the TAR II weekday-peak LOS transition year for forecast interpretation and mitigation planning.

The forecast places TAR II weekday peak at 0.69 in 2032, 0.04 above TAR. TAR II also reaches 0.60 in 2027, three years before TAR reaches the same value. This earlier loss of reserve supports staged intervention. Low-cost measures should begin before the service-grade decline, not after recurrent queues emerge. The first stage should include access marking, parking enforcement, bus-stop coordination, and peak-hour observation. The second stage should address median-opening geometry and deceleration storage if queues begin to affect through lanes.

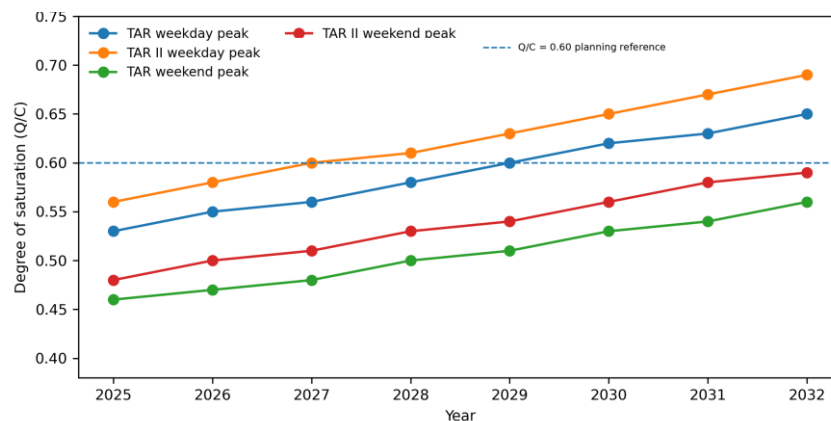


Fig. 5. Reported peak-period Q/C forecast for TAR and TAR II. The dashed line denotes Q/C = 0.60 as a planning reference, not an LOS threshold

The sensitivity analysis shows that the forecast conclusion is robust to moderate variation in the assumed traffic growth rate, although the amount of remaining operational reserve changes materially. Under 2.00% annual growth, the 2032 weekday peak Q/C is approximately 0.61 on TAR and 0.64 on TAR II. Under the 4.00% high-growth scenario, the values rise to approximately 0.70 and 0.74, respectively. Relative to the 2.98% source case, the 2032 peak Q/C changes by about -0.04 to +0.05. TAR II remains the more constrained segment in every scenario, so the need for monitoring and staged intervention does not depend on the single 2.98% assumption.

Forecast uncertainty still deserves explicit treatment. The 2.98% annual rate may not capture economic change, new developments, public transport service changes, or induced demand. The 2.00% and 4.00% sensitivity cases quantify how a plausible planning range changes the 2032 Q/C outcome, but they do not constitute probability-based confidence limits. A practical monitoring framework should compare observed annual peak flows with the forecast and update the intervention year when deviation exceeds a defined threshold, such as 10%.

Table 8. Sensitivity of 2032 weekday peak Q/C to annual traffic growth

Scenario	Annual growth	TAR peak Q/C	TAR II peak Q/C
Low-growth	2.00%	0.61	0.64
Source/base	2.98%	0.65	0.69
High-growth	4.00%	0.70	0.74

Note: Author-derived sensitivity analysis from the reported 2025 weekday peak Q/C values; capacity held constant.

3.6 Public transport and pedestrian access

The 2025 study reported a Teman Bus stop near Patria Artha Campus approximately 130 m from the development access. That distance is potentially walkable, but distance alone does not guarantee usable access. The external corridor lacks a continuous sidewalk, and users may need to cross or move along a high-volume divided collector. A safe connection requires a continuous path, accessible curb transitions, lighting, drainage, shade where feasible, and a controlled crossing aligned with the bus stop.

The internal plan provides 2 m sidewalks on both sides of 14 m rights-of-way in residential and mixed-use zones, 1.5 m sidewalks on both sides of 8 m residential rights-of-way, and 2 m sidewalks in the 20 m shophouse corridor. These dimensions establish a reasonable internal pedestrian network. The main weakness is the interface with Tun Abdul Razak Road. Without a protected frontage path and crossing treatment, the internal network terminates at the location with the greatest vehicle conflict.

Research on walkability and transit access shows that design quality, destination connectivity, and perceived safety influence walking and transit use alongside proximity (Saelens et al., 2003). The development should treat the 130 m connection as a project obligation (Ewing & Handy, 2009). The recommended package includes a direct walkway to the stop, high-visibility crossing markings, refuge or median treatment where justified, warning signs, lighting, and coordination with the road and transit authorities. The crossing location must avoid the U-turn queue influence area (Fong et al., 2023).

3.7 Parking demand and internal circulation

Table 9. Reported parking demand by land use

Land use	Gross area (m ²)	Required spaces (SRP)
Shophouse area	12,804	145
Commercial area	17,000	175
Total	29,804	320

The source estimated 145 parking spaces for the 12,804 m² shophouse area and 175 spaces for the 17,000 m² commercial area, giving 320 spaces. The calculation used land-

area units of 100 m². The original narrative occasionally described 128 and 170 as square metres, but they are dimensionless hundreds of square metres. Correct unit reporting is important because the erroneous wording would understate site area by a factor of 100.

The total was allocated to 214 motorcycle spaces, 101 car spaces, and 5 truck spaces. These shares differ from the observed road composition because parking demand depends on land-use users, space standards, and service requirements. The motorcycle allocation remains dominant and reflects local travel conditions. The five truck spaces require separate loading access so that commercial deliveries do not occupy the internal circulation road or queue at the external access.

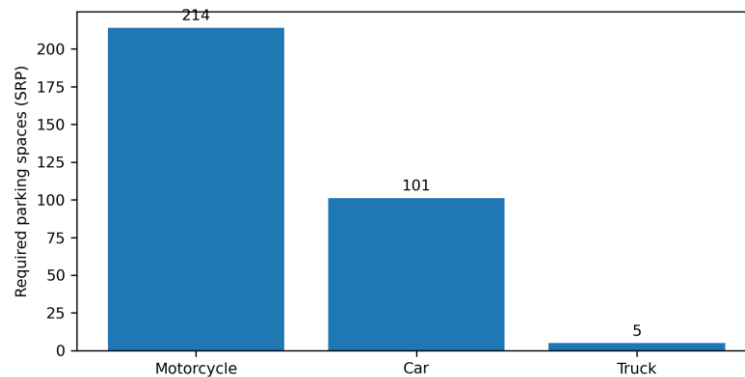


Fig. 6. Reported allocation of commercial parking demand by vehicle type

Parking provision should include management rules, not only a numerical supply. The site needs marked bays, motorcycle organization, accessible spaces, loading windows, turning clearance, and prohibition of parking within sight triangles and access throats (Manville & Shoup, 2005; Shoup, 2006). Parking spillover on Tun Abdul Razak Road would increase side friction and invalidate the capacity assumptions (Marsden, 2006). The literature also cautions that abundant free parking can reinforce private-vehicle demand. Management should therefore combine adequate off-street supply with transit and walking incentives (Saelens et al., 2003).

3.8 Traffic safety, construction logistics, and pavement risk

The principal operational conflicts occur at the site access, U-turn I, U-turn II, the commercial frontage, and pedestrian routes to public transport (Cervero & Kockelman, 1997). Potential crash patterns include rear-end collisions from sudden deceleration, side impacts during merging and turning, sideswipes near queue spillback, and vehicle-pedestrian conflicts (Wazirzada, 2023). The risk rises during the afternoon peak when the highest attraction and queue ratios occur. Road-safety research links access density, speed, street design, and pedestrian exposure with crash outcomes, supporting a design-led rather than enforcement-only response (Dumbaugh & Rae, 2009).

The proposed left-in/left-out control reduces direct cross-median conflicts at the access. It should be supported by channelization, advance warning, pavement arrows, delineation, and physical measures that prevent prohibited turns. Deceleration and acceleration space should be evaluated against actual approach speed and available right-of-way. CCTV can support monitoring, but cameras do not replace geometric design, lighting, signs, markings, or pedestrian protection.

Construction logistics create a separate risk. The source estimated 14,031 hauling trips at about 125 trips per day. Repeated heavy-vehicle movements can damage concrete slab joints, pavement edges, shoulders, and the access apron (Tan et al., 2025). Trucks also need wider turning paths and longer gaps, which can intensify U-turn and access interference (Ewing & Handy, 2009; Hasibuan & Mulyani, 2022). The construction traffic management plan should route trucks, prohibit movements during commuter peaks, control loads, clean

mud and debris, provide trained flaggers when required, and inspect pavement condition before, during, and after construction.

The staged mitigation matrix translates the findings into an implementation sequence rather than a list of isolated measures. Its practical value is that the intensity of intervention is matched to observed risk: low-cost management and safety measures are implemented before construction and occupancy, post-opening monitoring is used to verify whether forecast assumptions remain valid, and more costly geometric changes are reserved for documented queue spillback, repeated U-turn pressure, or faster-than-forecast growth on TAR II. This sequencing gives the project proponent and road authority clear decision points, reduces the risk of both under-mitigation and premature capital works, and allows mitigation timing to be adjusted as actual travel behavior emerges. The 2028 LOS transition should therefore be treated as an early planning horizon, while observed queue and Q/C thresholds remain the primary triggers for escalation.

Table 10. Recommended staged traffic-management and monitoring framework

Stage	Primary action	Timing
Pre-construction	Document pavement and shoulder condition; approve truck route; set delivery windows; install temporary signs and wheel-cleaning controls.	Before earthworks
Access construction	Build channelized left-in/left-out access; verify sight distance; provide lighting, markings, and drainage.	Before heavy site traffic
Opening	Complete internal sidewalks, frontage pedestrian link, crossing treatment, parking markings, loading bays, and bus-stop connection.	Before occupancy
Operations	Count traffic and U-turn queues during weekday afternoon peak; enforce no-parking zones; coordinate deliveries.	First 3, 6, and 12 months
Trigger-based	Review U-turn geometry and storage if queues enter through lanes or TAR II peak Q/C exceeds the monitored forecast.	As threshold is reached
Maintenance	Repair project-related pavement damage and refresh signs, markings, lighting, and pedestrian facilities.	Annual and after major damage

Note: Developed from the traffic impact findings and international access-management principles.

3.9 Study limitations and research implications

The study has four main limitations. First, it relies on secondary processed traffic data rather than original field records. The source does not provide raw classified traffic-count sheets, survey dates for individual observation periods, or confidence intervals. Consequently, the analysis cannot independently verify the original counts, quantify sampling error or day-to-day variability, assess temporal representativeness, or estimate statistical uncertainty in the reported traffic volumes and derived performance indicators. The results should therefore be interpreted as deterministic estimates derived from reported source outputs rather than statistically inferred population parameters. Reproducibility is limited to the reported inputs, equations, assumptions, and journal-level calculations, not replication of the original field survey. Second, the 77.3%/22.7% directional distribution is an analogy-based proxy transferred from a comparable residential development because site-specific origin-destination data were unavailable before occupancy. This assumption may overstate or understate direction-specific loading if future Sunville residents have different employment, education, or activity destinations. Third, the same maneuver-time table appears for both U-turns, which limits site-specific comparison. Fourth, although the forecast now includes deterministic 2.00%, 2.98%, and 4.00% growth scenarios, the source provides no statistical basis for a probability distribution or confidence interval around the 2.98% rate, and microsimulation of access interactions remains unavailable.

These limitations do not invalidate the baseline findings, but they define the next research steps. A post-opening study should collect at least two representative weekdays and one weekend day, measure 15-minute classified flows, approach speed, U-turn gaps, queue length, pedestrian movement, bus activity, parking occupancy, and delivery patterns. Video data can support conflict analysis and motorcycle trajectory measurement. A calibrated microsimulation could then test alternative access geometry, U-turn storage, crossing locations, and occupancy stages.

The integrated approach used here offers a practical model for similar peri-urban projects. Link capacity alone would classify the opening-year impact as minor. U-turn ratios, directional concentration, pedestrian discontinuity, motorcycle dominance, parking demand, construction logistics, and pavement exposure reveal where the actual management burden lies. The methodological contribution is this integration across scales and functions, from segment performance to point-specific access operations and multimodal management. Its reproducibility value comes from a transparent chain of reported inputs, equations, recalculated summaries, and documented assumptions. For decision makers, the staged framework converts these findings into auditable permit conditions: measures can be assigned to pre-construction, opening, routine monitoring, and trigger-based escalation, with responsibility shared between the developer and relevant road and transport authorities. This makes the assessment operationally useful because it links approval to measurable performance rather than to a one-time forecast, while preserving flexibility to intensify or defer interventions as monitored conditions change.

3.10 Implementation and monitoring protocol

The development should convert the analytical results into permit conditions that can be checked after construction. The first control point is the access opening. Before occupancy, the project proponent should submit as-built dimensions for the access throat, channelization, sight triangles, pedestrian route, lighting, drainage, signs, and pavement markings (Basri et al., 2017). A joint field inspection with the road and transport authorities should confirm that the constructed access matches the reviewed design and that no utility pole, advertising structure, landscaping element, or informal parking space obstructs visibility. This verification is important because a small deviation in access geometry can change turning speed and queue storage even when the link-level Q/C remains unchanged.

The second control point is the first year of operation. Monitoring should focus on the weekday afternoon period from 15:00 to 18:00 because the production peak, attraction peak, and highest U-turn queue ratios occur within this window. Data collection should use 15-minute intervals and classify motorcycles, medium vehicles, and heavy vehicles. Observers should record through flow, site entries and exits, U-turn demand, maximum queue length, queue duration, blocked-lane events, bus stopping, pedestrian crossings, delivery activity, and parking spillover. The first post-occupancy survey should also estimate the observed Makassar/Gowa directional split so that the transferred 77.3%/22.7% assumption can be recalibrated when necessary. The survey should be repeated at three, six, and twelve months after occupancy to distinguish temporary opening effects from stable travel patterns.

The third control point is a threshold-based response system. The project team should investigate immediate operational changes when queues from U-turn I enter a through lane, when the medium-vehicle queue ratio exceeds 0.58 on repeated survey days, when observed project trips exceed the study estimate by more than 10%, or when TAR II weekday peak Q/C rises faster than the forecast trajectory. The first response should prioritize management measures, including delivery scheduling, parking enforcement, bus-stop coordination, clearer lane assignment, and trained traffic personnel during exceptional demand. Geometric modification should follow when recurring evidence shows that management alone cannot prevent queue spillback or unsafe merging.

The fourth control point is multimodal performance. The proponent should inspect the pedestrian connection to the reported nearby bus stop at the same intervals used for traffic

monitoring. The inspection should assess continuity, effective width, surface damage, standing water, obstruction, lighting, crossing visibility, and conflicts with motorcycles. Public transport access should remain direct and should not require pedestrians to walk through parking aisles or loading areas. Counts of pedestrians and transit users can reveal whether the proposed facilities reduce private-vehicle dependence. This evidence can also support later adjustment of parking management and commercial delivery rules.

The fifth control point is construction and pavement accountability. The project should maintain a daily log of heavy-vehicle arrivals, departure times, estimated loads, route compliance, and any road-cleaning action. Photographic pavement surveys should document concrete slabs, joints, shoulders, drainage edges, and the access apron before construction, at regular intervals, and after major hauling phases. The responsible party should repair project-related damage before it creates a safety hazard or accelerates water intrusion. Together, these five control points create an adaptive management system. They connect permit approval with field evidence, assign responsibility, and allow mitigation to respond to actual traffic behavior rather than relying solely on a deterministic 2032 forecast.

4. Conclusions

The affected Tun Abdul Razak corridor had a reported adjusted capacity of 6,314.9 passenger-car units per hour. Existing weekday peak degree of saturation was 0.52 on TAR and 0.55 on TAR II, increasing to 0.54 and 0.57 in the opening development scenario; therefore, the project did not immediately change the reported level of service. TAR II nevertheless remained the more constrained segment, while U-turn I produced the strongest local pressure, with a maximum medium-vehicle queue ratio of 0.58 during the 17:00-18:00 weekday period. Development travel was concentrated toward Makassar (77.3%), and motorcycles represented 84.1% of observed daily traffic, reinforcing the need for locally calibrated access and safety management. By 2032, weekday peak Q/C was projected to reach 0.65 on TAR and 0.69 on TAR II.

The earlier 2028/2029 forecast-year inconsistency for the TAR II weekday-peak LOS transition has been resolved by applying 2028 consistently throughout the manuscript. Sensitivity testing further showed 2032 weekday peak Q/C ranges of 0.61-0.70 on TAR and 0.64-0.74 on TAR II under annual traffic growth rates of 2.00%-4.00%, confirming that the timing and severity of future pressure are growth-sensitive. These forecast years should therefore be treated as planning horizons rather than fixed intervention dates. Mitigation should be staged and triggered primarily by observed conditions, including queue spillback into through lanes, repeated U-turn queue ratios above the current benchmark, project trips exceeding estimates by more than 10%, or TAR II weekday peak Q/C rising faster than the monitored forecast trajectory.

Management measures should be implemented first, with geometric modification introduced only when recurring field evidence shows that operational controls are insufficient. The recommended package includes channelized left-in/left-out access, adequate U-turn storage and sight distance, continuous pedestrian access to public transport, controlled crossings, managed parking and loading, peak-hour delivery restrictions, construction-truck controls, pavement inspection, and periodic traffic monitoring. The study's contribution is an integrated and auditable decision framework that links segment capacity, U-turn operations, travel demand, multimodal access, parking, safety, construction logistics, and pavement risk while emphasizing adaptive, threshold-based intervention rather than reliance on a single deterministic forecast.

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Author Contribution

Conceptualization, I.A. and M.H.; Methodology, S.B.; Formal Analysis, M.H.; Data Curation, S.B.; Writing - Original Draft Preparation, I.A.; Writing - Review & Editing, S.B. and I.A.; Visualization, S.B.; Supervision, I.A.; Project Administration, S.B.

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Not available. This study did not involve humans, animals, or clinical/public health intervention research.

Informed Consent Statement

Not available.

Data Availability Statement

The quantitative inputs used in this article are derived from the 2025 Sunville Residence traffic impact assessment. The manuscript reports the source values, equations, units, scenario assumptions, and derived summaries needed to reproduce the journal-level calculations presented here. The original raw traffic-count sheets, survey logs, speed distributions, crash records, and microsimulation files were not available to the authors and therefore cannot be provided. Access to additional project records is subject to permission from the project owner or data provider.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the authors used generative artificial intelligence to assist in language structuring, academic organization, and formatting. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Biographies of Authors

Irwan Amar, Safety Engineering Study Program, Institut Teknologi dan Kesehatan Tri Tunas Nasional, Makassar, South Sulawesi 90235, Indonesia.

- Email: irwanamar92@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: <https://scholar.google.com/citations?user=G76kjIAAAA&hl=id>

Syamsul Bahri, Department of Public Health, Universitas Mega Buana Palopo, Palopo, South Sulawesi 91913, Indonesia.

- Email: syamsulbahri260280@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: <https://sinta.kemdiktisaintek.go.id/authors/profile/6945915>

Muhammad Hatta, Public Health Study Program, Sekolah Tinggi Ilmu Kesehatan Makassar, Makassar, South Sulawesi 90241, Indonesia.

- Email: muhhatta772@gmail.com
- ORCID: 0009-0003-8543-9361
- Web of Science ResearcherID: N/A
- Scopus Author ID: 59417139200
- Homepage: <https://sinta.kemdiktisaintek.go.id/authors/profile/6199897>